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Energy-Efficient Passive Solar House Designs for Canada

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PREFACE

Background

The oil embargo of the 1970's caused people to look at the potential of solar energy, and other conservation and renewable energy sources, to reduce dependence on fossil fuels. Since then, Canada has become a leader in energy-efficient housing and examples of our energy-efficient housing technology have been exhibited around the world.

A major component of an energy-efficient house is passive solar energy; typically 20% - 25% of the annual space heating energy needs of an energy-efficient house are met by the sun. Until recently, the building community has been reluctant to increase the passive solar contribution much above this level. Refinements in analytical techniques and improvements in window technology, together with advancements in mechanical equipment, now make it possible to double the amount of passive solar energy an energy-efficient house can use, while maintaining occupant comfort. This means that new energy-efficient homes may have greater emphasis placed on the passive solar components, more solar amenities, such as glazed sunspaces, for the occupant and lower purchased energy consumption.

Advantages of passive solar design

The concept of energy-efficient passive solar design has great appeal for the homebuyer. Builders have found that large windows, skylights and solariums are good selling features. Low energy costs are a priority for most buyers. Other components of solar design, such as good distribution of daylight, spacious open stairwells and decorative masonry feature walls, are to be found as selling features in many conventional new homes.

Designers who may have found passive solar design to be restrictive or ineffective in the past will discover that the new highly insulative glazings permit a greater range of effective window orientations; also the current analysis tools are accurate and, for the most part, simple to use.

In addition to the attractive architectural features, passive solar designs offer other advantages. The passive solar home should provide a greater level of thermal comfort than conventional homes— more even temperatures, no drafts, comfortable humidity levels. Indoor air quality should be superior because the energy-efficient passive solar home has a controlled ventilation system to provide a continuous supply of fresh air. And the energy performance should be as good as or better than any other energy-efficient house of the same size and location.

How to Use This Book

Although much has been written about energy-efficient construction, there is little up-to-date information about passive solar design for Canada. This book is a first step in redressing the balance.

The book is intended for designers, builders and owner-builders. Part I introduces the principles of passive solar design. It does not form a how-to manual but does provide design guidelines and refers to the detailed analytical tools required for design.

The second part of the book contains twenty-four simple, direct-gain energy-efficient passive solar house designs. Working drawings for construction may be prepared from the designs using energy-efficient construction practise suitable for the region, and following the guidelines presented in Part I.

CHAPTER 1: INTRODUCTION

Passive solar homes provide great opportunities for sunny windows, greenhouses and solariums but a good solar house is considerably more sophisticated, and effective, than a house that just has lots of south-facing glass. An energy-efficient passive solar home provides a comfortable, attractive, even luxurious environment; it makes good use of the sun's energy for heating and lighting, and reduces the need for purchased fuel. On the other hand, incorrectly designed passive solar houses can be uncomfortable due to glare or extreme temperature swings and may have increased fuel bills. Therefore it is important to understand the principles of passive solar design when designing or choosing a solar home.

Solar Radiation

Anyone who has sat by a sunny south-facing window on a cold winter's day has felt the effects of passive solar heating. The sun's energy passes through the glass in the form of short-wave light. When the light strikes an opaque object it is absorbed and converted to heat. Because the winter sun is low in the sky, the solar radiation strikes vertical window glass at close to 90 degrees and the sunlight can penetrate deep into the room. During the summer months when extra heat is undesirable, very little direct sunlight can penetrate the house through a vertical south window because the sun is high in the sky. Thus the solar energy is available to a house in the winter months when it is needed but does not overheat the house during the summer.

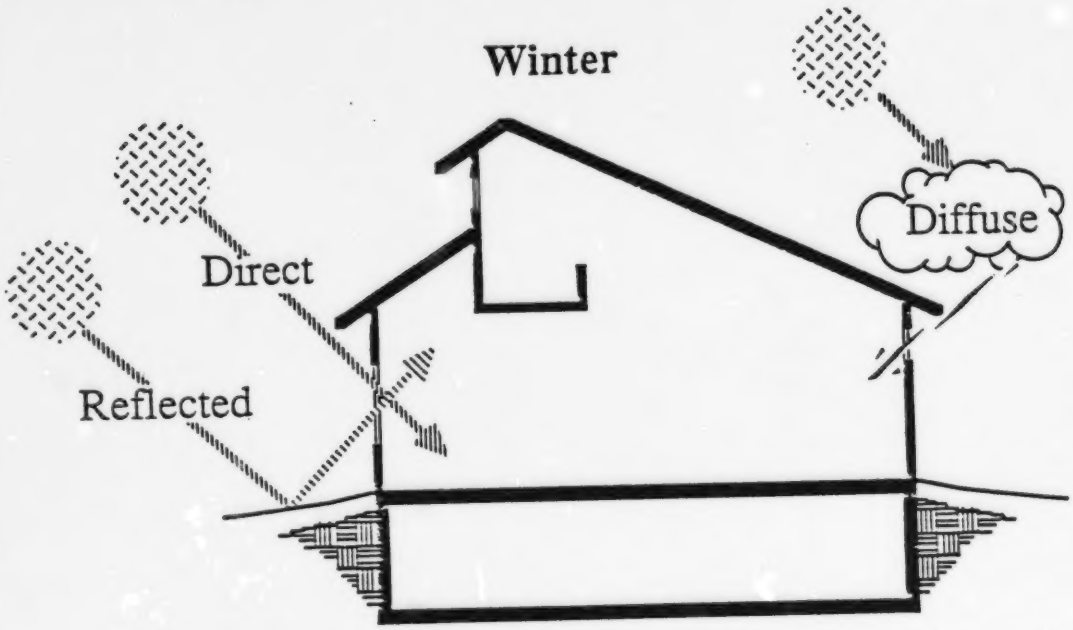
Direct sunlight generally provides the greatest proportion of the useable heat but **diffuse** radiation from the sky on an overcast day and **reflected** light from snow on the ground around the house can also supply useful energy.

Figure 1

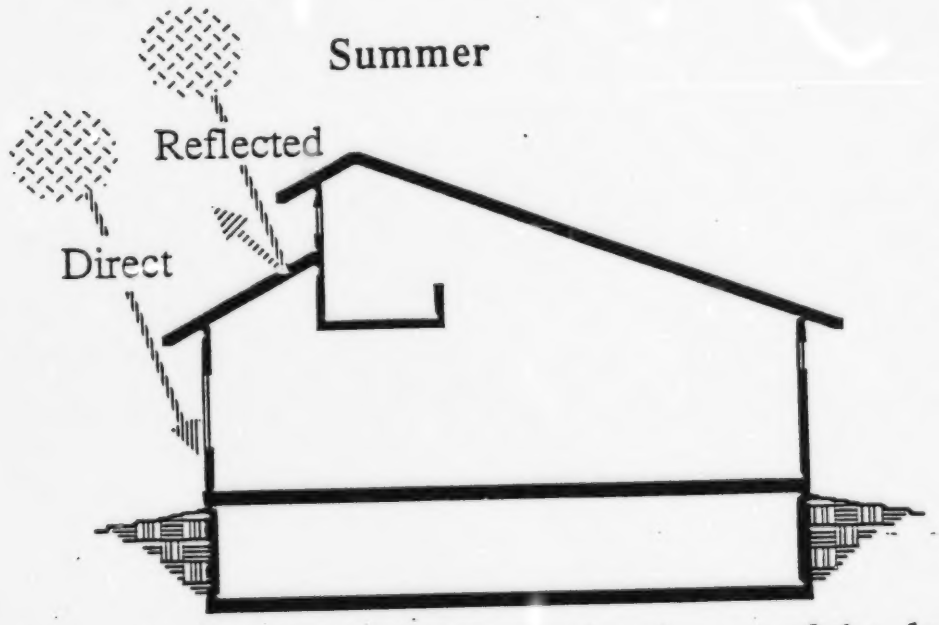
Solar Contribution

Most houses are partially heated by the sun. The amount of solar heat provided during a heating season is called the **Solar Contribution** (or Solar Fraction). This is expressed as a percentage of the **Total Space Heating Load** of the building during the same period. The bottom line, the homeowner's fuel bill, is the difference between the total space heating load (less internal gains from occupants, lights and appliances) and the solar contribution.

Figure 1: Solar Radiation



In winter, solar radiation enters the house predominantly by direct rays but to a significant degree by reflected rays and diffuse radiation scattered in the atmosphere striking all surfaces.



In summer, the radiation is overhead most of the day with little penetration through vertical windows which are easily shaded with overhangs.

Figure 2

The solar contribution may be used to assess a house at the design stage. As Figure 2 indicates, it is theoretically possible to achieve solar contributions approaching 100%, but to do so with current technology is impractical. An achievable goal is to utilize about one quarter of the available energy, because about half of the available solar energy is lost through reflection and poor transmission through the glass, and half of the remaining is available when it is not needed and cannot be stored. The annual solar contribution for a passive solar house is typically in the range of 25% - 40%. The limiting factors are the climate, the window thermal performance and the ability of the house to store solar energy. These percentages are relative and a house whose total annual heat losses are high will have higher heating bills than a house with more modest losses, even if a higher proportion of the heat is provided by the sun. The overall energy performance of a design is ultimately more important than the solar contribution.

Elements of Passive Solar Utilization

A passive solar system has four major components:

1. **Solar Collection:** The objective is to select the glazing orientation, area and type which gives good energy savings. Although a south-facing window admits energy to the house, it also allows heat to escape; conventional windows are poor insulators. Passive solar designs must employ glazings and window orientations that ensure a net gain to the house— the solar gains must exceed the heat losses through the window over the course of a heating season. If there is adequate heat circulation and thermal storage to accommodate the solar gains, a window which provides a net heat gain to the building performs better than a well-insulated wall!

   Beyond a point, adding more south glass will not improve the performance of a passive solar home. There is a limit to the amount of solar heat a building can use and if that limit is exceeded the occupants may find the house too warm during the day and too cold at night. Moreover, too much south-facing glass can mean higher fuel bills. Apart from providing heat, windows also provide natural light, ventilation, architectural character and opportunities for indoor plant growth. If more window area is needed, measures must be taken to ensure thermal comfort and performance.

2. **Heat Distribution:** Only a proportion of the heat admitted to the building can be used immediately; the rest must be circulated throughout the house or stored for later use. The passive solar house is designed for good heat distribution and natural air circulation, often assisted by fans or blowers.

Figure 2:

South Window Area Receiving 40 GJ of Solar Energy During the Heating Season

Location	Area (m2)
Winnipeg	14.1
Swift Current	14.6
Edmonton	14.9
Fredericton	16.0
Ottawa	16.1
Halifax	17.4
Montreal	17.4
Charlottetown	17.4
Toronto	18.9
St. John's	22.0
Vancouver	23.2

Most of the house designs in this book have a heating load of 40 GJ (Gigajoules) of energy per year. The chart indicates the size of solar aperture that receives 40 GJ in various locations. In practice, only a fraction of the incident radiation can be used due to losses in transmission through the glass, reflectance from inside, and the limits of storage capacity.

3. **Storage:** The nature of solar radiation is such that thermal storage, whether intentional or not, is an integral part of every passive solar house. The thermal storage provided by conventional building materials— plasterboard, concrete block, plywood etc— may be increased if necessary. Heavy building materials such as masonry and tile or double layers of plasterboard may be used in rooms receiving direct sunlight to store heat. For example, Designs 17 and 18 use concrete block party walls for thermal storage. Design 9 uses a double layer of drywall and a brick fireplace wall. Glazed mass walls (Trombe walls) can be used on the south walls of buildings. Solar-heated air may be circulated through hollow concrete floor slabs or rock storage bins. Water-to-air heat pumps can be used to provide highly- efficient remote water storage which can heat the house or domestic hot water.

4. **Energy Conservation:** A passive solar system will not function effectively unless the house is designed to contain the collected heat. Conservation levels such as those required to meet the R-2000 standard should be employed. This standard involves the use of high levels of insulation, airtight construction techniques, controlled ventilation and an efficient heating system. Passive solar designs use somewhat less insulation than a non-solar design to meet a given energy budget. However, for comfort, safety and long-term energy savings, the house should incorporate a complete package of conservation features. The designs in this book should be built to the National Building Code 1983 Measures for Energy Conservation or better.

Design Integration

A passive solar design usually employs several measures in combination to achieve optimum performance. For example, Design 1 would perform best with ceramic tile floors in the south-facing entry and a double layer of plasterboard in the south zone of the house for thermal storage. The double-height entry permits air to circulate naturally but the natural circulation is assisted by a high air-return to the furnace, located at the top of the stairwell.

Design Tools

Much of the art of passive solar design involves finding the right balance between glazing type, size and location, thermal storage, air circulation and building envelope efficiency. The guidelines presented in the following chapters should be sufficient for preliminary design purposes. Once preliminary drawings have been prepared, a detailed analysis should be done to fine-tune the design.The designs in this book have been through this engineering process and may be directly translated into working drawings using good, energy-efficient detailing, however it is recommended that analysis be done on the working drawings to ensure good performance with the chosen glazing and energy-efficiency measures. The following thermal analysis tools may be used:-

ANNUAL SPACE HEAT ENERGY GRAPH

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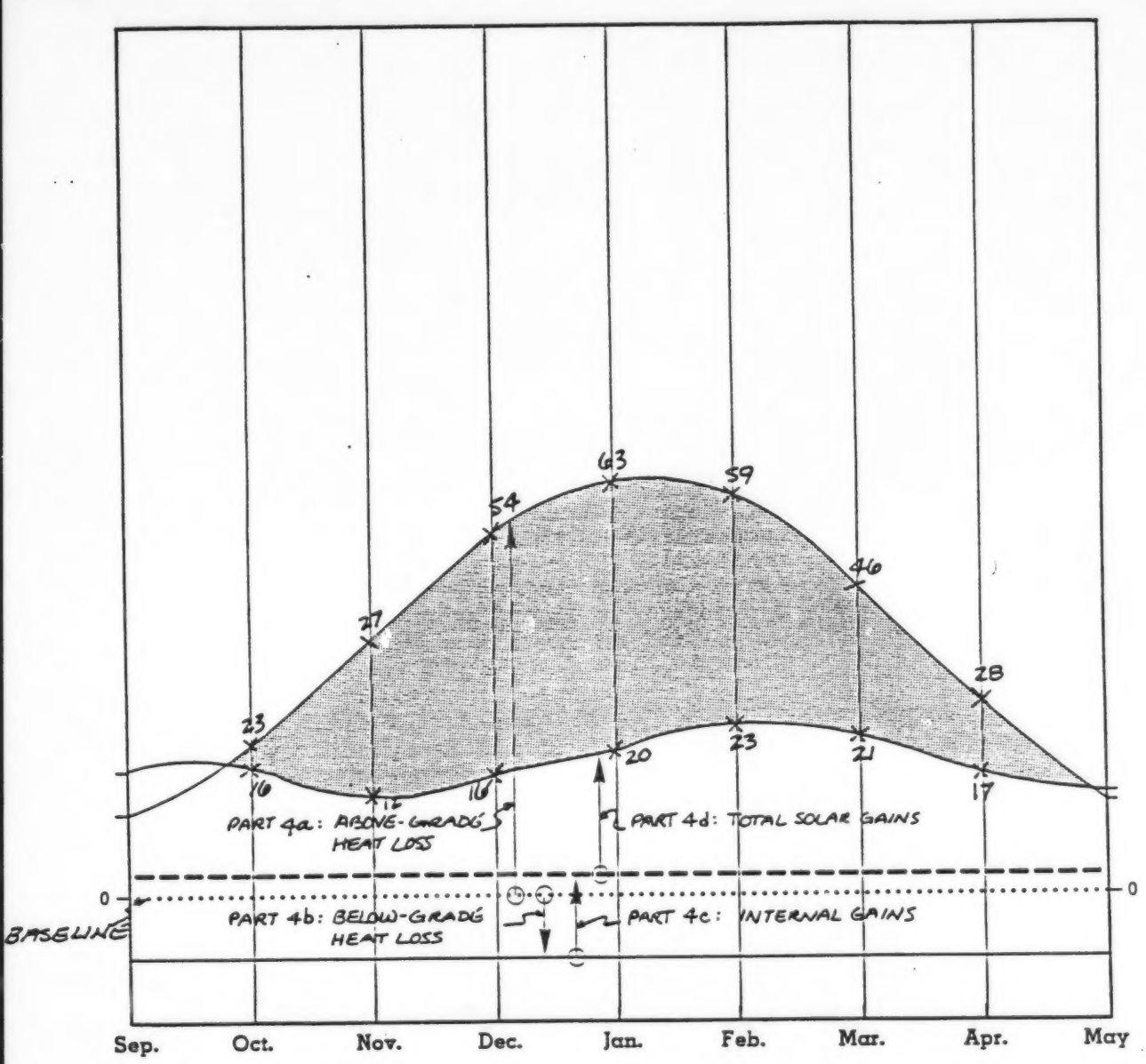


Scale: 1 mm = 1 MJ/m² month

Summary			
Total heat losses minus internal gains	62	310	MJ/m²
Useful solar gain	59 × 64	125	MJ/m²
Annual energy consumption	65	37.7	GJ/yr
Annual energy cost	66	419	$

Figure 3

Manual Method Using GRAPHEAT.
GRAPHEAT is a simple method for quickly estimating passive solar performance. Using a series of graphs and tables such as those shown in figure 3, the technique allows the designer to calculate the total heat loss for a house, the total solar contribution, and the expected maximum indoor temperature swing due to solar heat gain. GRAPHEAT was used to calculate the performance of the designs in this book. A companion technique— GRAPHSHADE— allows the designer to determine shading effects.

The GRAPHEAT method is outlined in two CMHC publications: GRAPHEAT and GRAPHSHADE. (See the Further Readings section at the end of this book for ordering information.)

Computer Software — HOT-2000
HOT-2000 is the easiest to use and quickest microcomputer program. It is also the official analysis tool of the R-2000 program and a design must meet the R-2000 Energy Budget, determined by HOT-2000 analysis, as the first step in registration as an R-2000 house. This program does not yet predict temperature swings.

Computer Software— ENERPASS
ENERPASS is a powerful, detailed and sophisticated analysis tool which gives hour by hour simulations in addition to seasonal totals. It is suitable for analysing complex designs or for checking outputs from other programs, particularly when unusual design strategies are employed.

Other Software programs
There are several U.S. programs on the market which can provide thermal analysis for passive solar houses. They include F-Load, SERI RES, and CALPAS 3.

Summary

Passive solar houses are designed to make effective use of the sun's energy and to minimize the use of purchased energy. A careful design and analysis process should be followed, which involves:

1. selection, sizing and location of windows (solar collectors).
2. design for distribution of heat throughout the house
3. inclusion of thermal storage.
4. integration of the passive solar features and other energy conservation measures with the aid of performance analysis tools.

The following four chapters describe these aspects in more detail.

Figure 4a:

Seasonal Net Gains vs. Orientation

(Assumes 28% Frame/Window Opening)

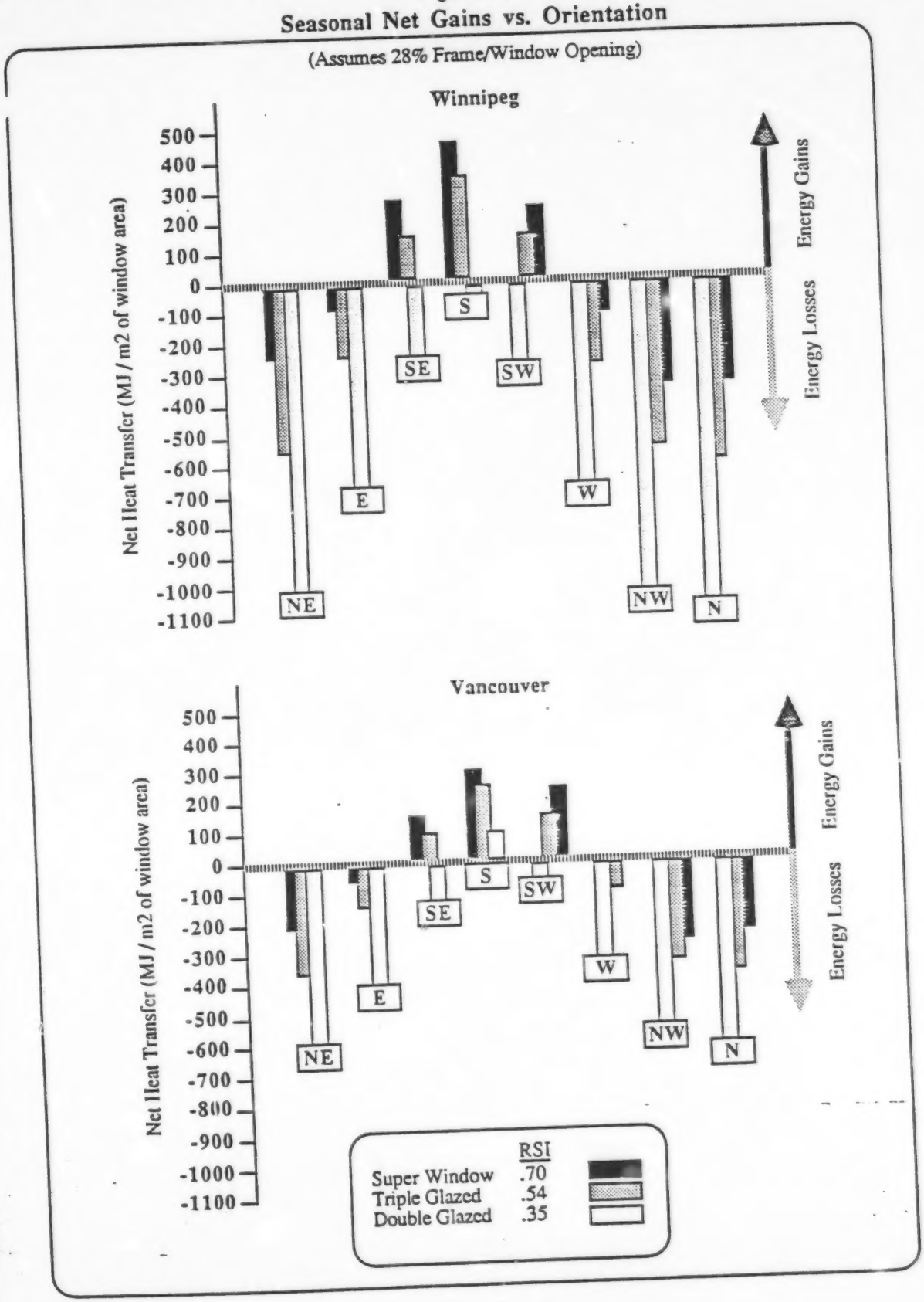
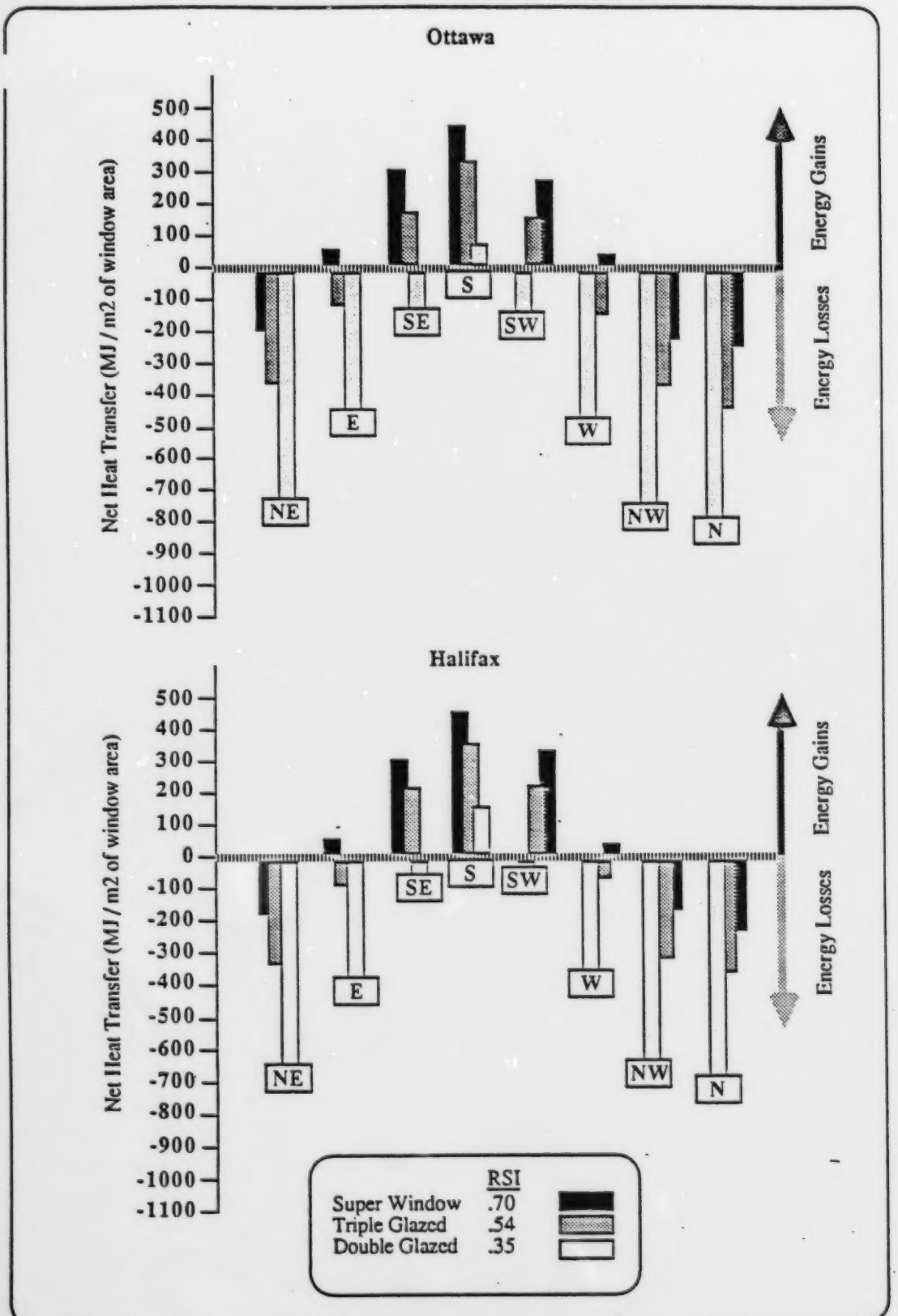


Figure 4b:

Seasonal Net Gains vs. Orientation



CHAPTER 2: COLLECTING SOLAR HEAT

Introduction

Windows and other glazed openings are the solar collectors of a passive solar house. Until recently, houses with lots of glass, even south-facing glass, would generally be less energy-efficient than a well-insulated house with very little glass. Advances in window technology and mechanical system design together with the availability of easy-to-use thermal analysis tools now make it possible to build highly energy-efficient passive solar houses. But, for the house to function properly and be comfortable to live in, the glazing must be carefully considered.

Net gain and solar orientation

Glass admits solar energy to the house, but it is a poor insulator. An insulated wall might have a thermal resistance (RSI) of about 3.5; double glazing with a 12mm airspace has an RSI value of 0.35, it is ten times less insulative than the wall. A window must admit more heat than it loses over a heating season to provide a net gain to the house.

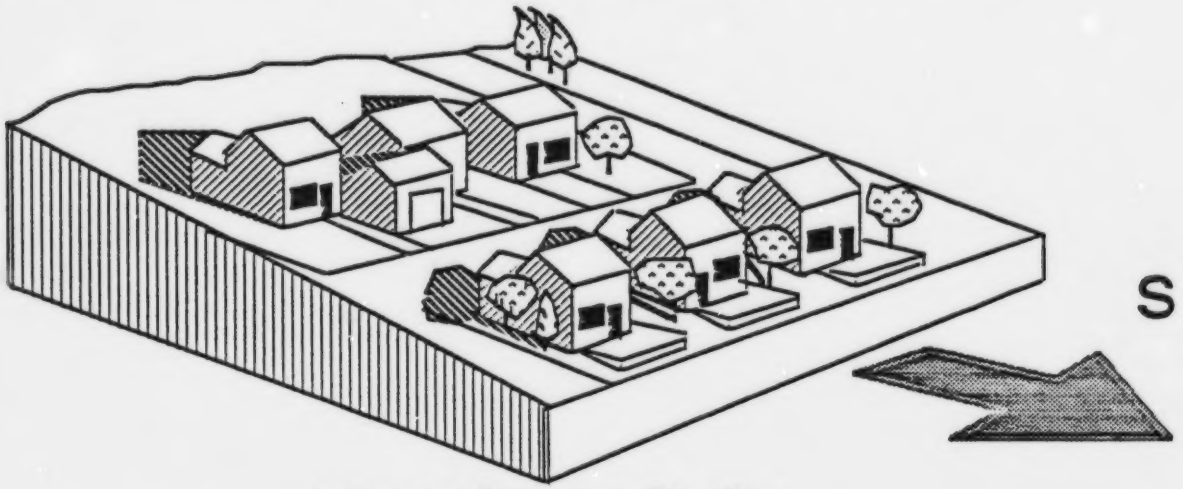
Windows do not have to face due south to function effectively as solar collectors but the greater the deviation from south, the more insulative the window must be to provide a net gain. For example, in the Ottawa region, east or west-facing high-performance triple glazing will provide a very slight net gain whereas double glazing will lose energy. Some glazings now under development will provide a net gain in any direction. Figure 4 shows the seasonal net gains or losses for windows which face in different directions.

Figure 4

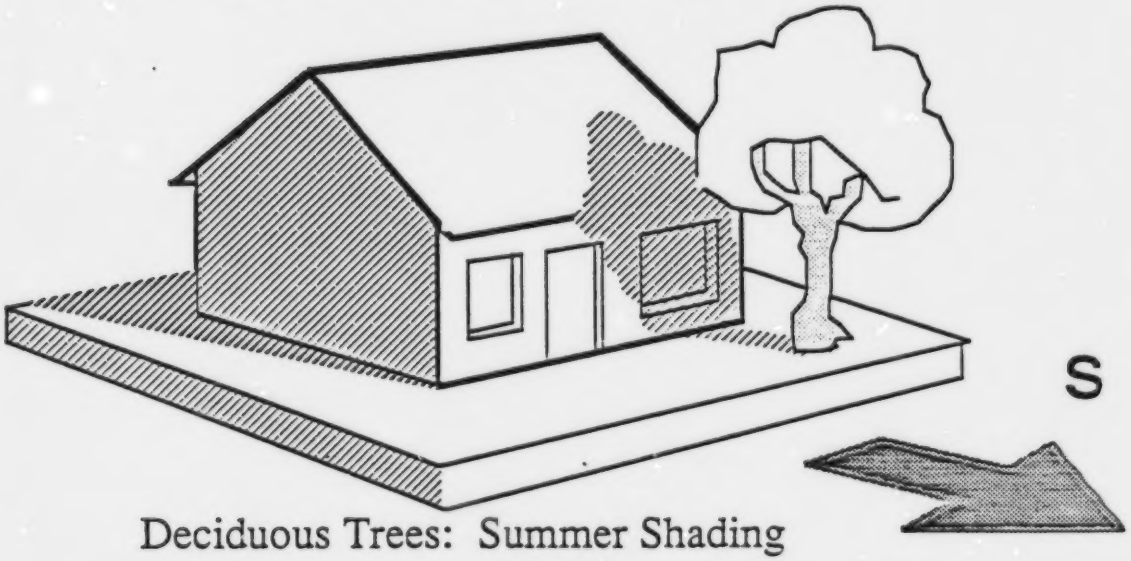
The preferred solar orientation is southwards. In addition to the net gains, the following factors should also be considered:

1. It is easy to control excess summer gains through south-facing windows because there is little solar penetration. Additional shading can be provided by awnings or other devices. It is more difficult to shade and therefore control solar gains for easterly or westerly windows.
2. Non-south windows distribute winter gains unevenly during the day. For instance, a west window provides little solar gain in the morning but a lot in the afternoon— generally an undesirable situation. On the other hand, an east window receives the majority of its daily solar gains during the morning. Some east windows may be advantageous, since the heating requirement is likely to be greater in the morning, due to cool outside temperatures and because the house temperature, after night thermostat setback, is cooler in the morning.

Figure 5: **Shading**



Adjacent Structure Shading



Deciduous Trees: Summer Shading

Deciduous Trees: Winter Shading

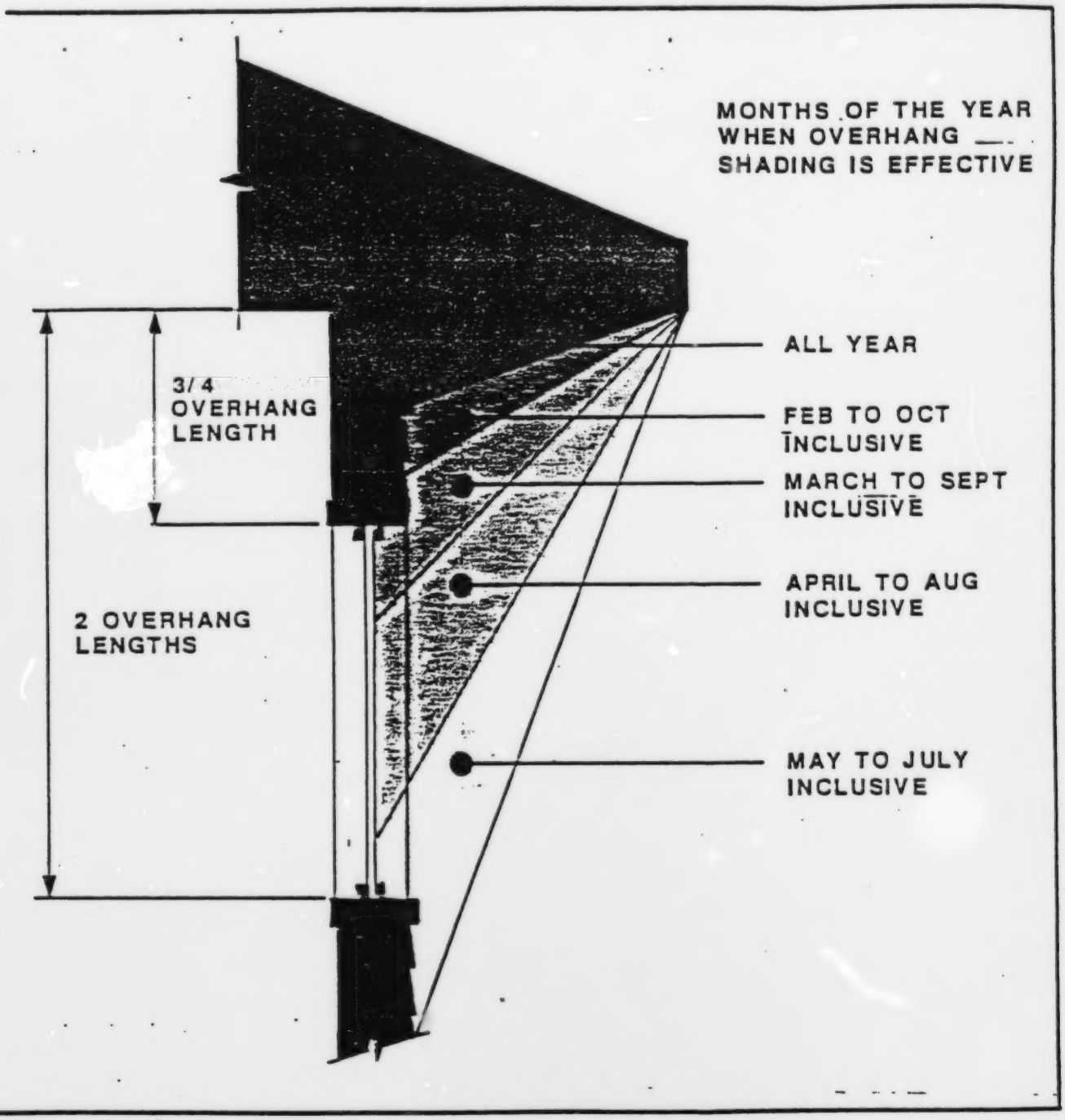


EXHIBIT 5
SEASONALLY-VARYING SHADING EFFECT
OF OVERHANGS ON SOUTH-FACING WINDOWS

Rules of Thumb for Solar Orientation:

- **Preferred orientation: the major portion of the window area should face between 15 ° west of south and 20° east of south.**
- **Acceptable orientation: windows should face within 30° east or west of south.**
- **If highly insulative windows are used, the window orientation becomes less critical and it may be prefererable to locate the windows so that all areas of the house receive good daylight, and therefore direct gains.**
- **North-facing windows should be minimized, regardless of the type of windows used.**

Temperature Swing

When sunlight enters the house and strikes a solid object, the object becomes warm. The warm surface in turn warms the air around it. The result is that the sunny part of the house very quickly becomes noticeably warmer than the rest of the house. The heating process continues as long as the sun is shining. Gradually, even without any forced-air circulation, the whole house becomes warmer and the part of the house receiving the sunlight becomes hot.

Rules of Thumb for Temperature Swing:

- **In mid-winter, a small temperature swing of up to 6° C is acceptable.** A large temperature swing of 8° C or 10° C is not. As soon as the house begins to be too hot, the occupants open windows to vent the heat. Effective solar gains cease and heat already collected is lost. For analytical purposes, any solar gains which result in a temperature swing of more than about 5° or 6°C are considered to be vented outside. Each design in this book has a calculated maximum temperature swing value.

- **Large expanses of west-facing glass should be avoided.** West and sometimes east-facing windows may cause overheating problems, particularly in summer, spring and fall. This overheating is caused by the low angle of the sun in the western (or eastern) sky. During late afternoon and evening (morning) the sunlight can penetrate deep into the room through west (east) windows and heat the house as effectively as the mid-winter sun at noon. During the marginal months and in summer, little of this heat is needed; the rest must be vented or stored before overheating occurs.

Winter Shading

During the heating season, southern shading is almost always unwanted and should be avoided as far as possible. Unless the lots are large, east-west streets are preferable for passive solar homes, since buildings and trees on adjacent properties can be a problem in the case of north-south streets. If part of the south elevation will be shaded, the windows should be located as far as possible on the unshaded portion. In some cases it may be possible to rotate the building a few degrees to reduce or eliminate unwanted shading. It is better to have windows which receive some sunlight, even if it is not south light, than south-facing windows which receive little due to shading.

Figure 5

Rule of Thumb for avoiding Winter Shading:

- **Select a site on the north or south side of an east-west street without southern obstructions.** Sun path charts may be used to determine the amount of shading a site will receive at different times of year.

Summer Shading

One objective of good passive solar design is to prevent overheating during summer, spring and fall, when there is little requirement for heat. The following methods may be used to reduce the amount of sunlight which enters the house, but fixed shading devices should be used with caution because they block daylight at all times of year.

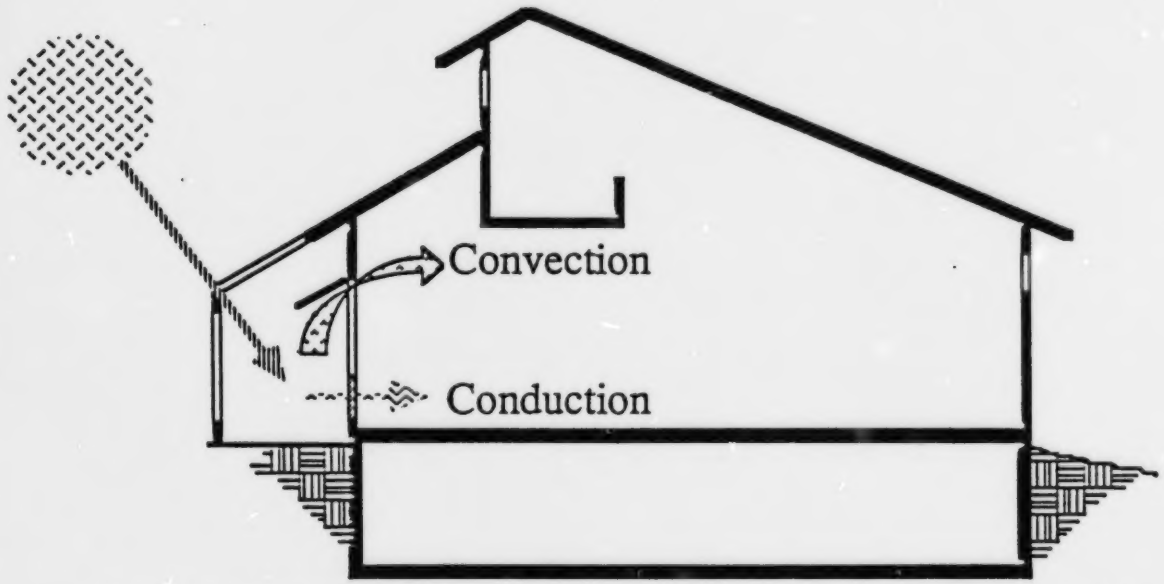
Awnings. Overhead retractable awnings are a good method of limiting the entry of sunlight through south, southeast and southwest windows. The awning can be folded up against the house or removed when more heat or light is needed.

Figure 6

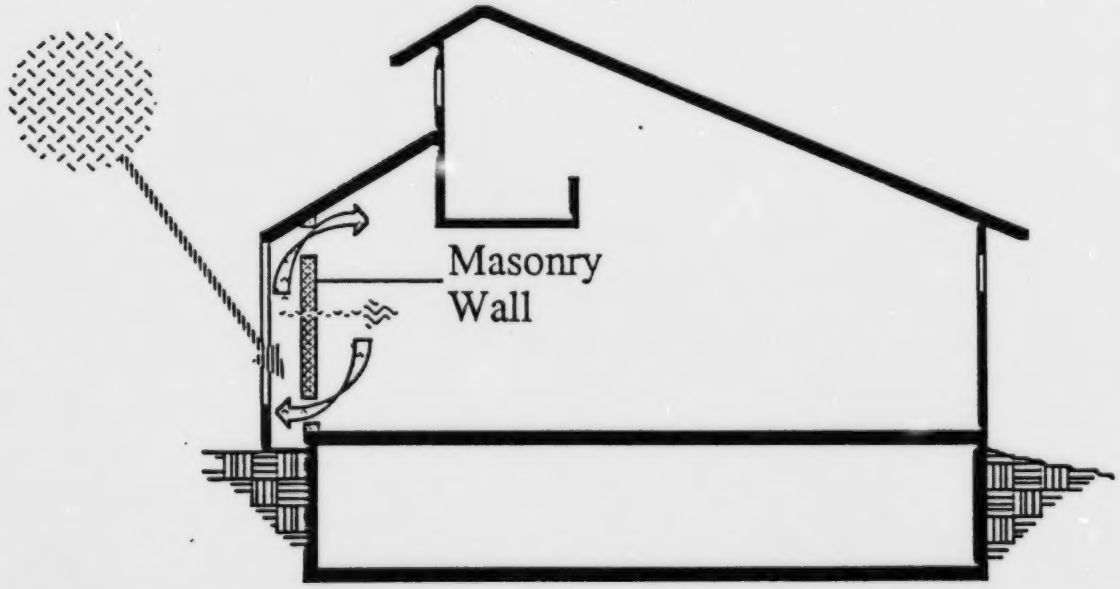
Overhangs. Architectural elements such as eaves and balconies may be used to provide permanent south window shading. They must be correctly sized so that they do not obstruct the entry of the winter sun, or block too much daylight. Wing walls or trellises may be used to block east and west sunlight.

Blinds and curtains. Blinds and curtains with a white or reflective backing provide a degree of shading for windows of any orientation and have the advantage of being easy to operate from inside. However, because they are inside the house and therefore do not prevent the entry of sunlight, conventional blinds and curtains do not function as effectively as exterior devices. Blinds or sunscreens which fit between two layers of window glass work better as shading devices.

Figure 7: **Indirect Gain**



Attached sunspaces or solaria may deliver solar gain to the heated space by natural or forced convection or by conduction through the interposed wall



A Trombe wall consisting of glass over an absorbing surface and thermal mass wall delivers heat by natural convection and conduction

Low transmissivity glazing. Mirror glass, bronze glass and tinted glass etc. allow a reduced amount of light to pass through and have been used for many years on commercial buildings to control overheating. The disadvantage is that the glass also blocks needed winter sun. "Smart " glazings which alter their transmissivity are under development, their use may eliminate the need for other shading devices.

Landscaping. Vegetation is a good way to block or filter sunlight to east and west windows. Deciduous or evergreen trees and tall shrubbery may be planted to block direct sun morning and evening year round. Deciduous trees on the south side of a house also provide summer shading. In the winter a large deciduous tree creates considerable unwanted shade and may reduce the available sunlight by as much as 50%. Ground cover around a house will reduce the amount of reflected light and also has a slight cooling effect.

Direct gain

Direct gain is the process by which sunlight heats the room which it enters. Generally, the south rooms of a house are heated by direct gains and the north rooms are heated indirectly by solar-heated air which is circulated from the south to the north side of the house. All the designs in this book use direct gain to the south zone of the house. Direct gain is the simplest and most effective method of solar collection.

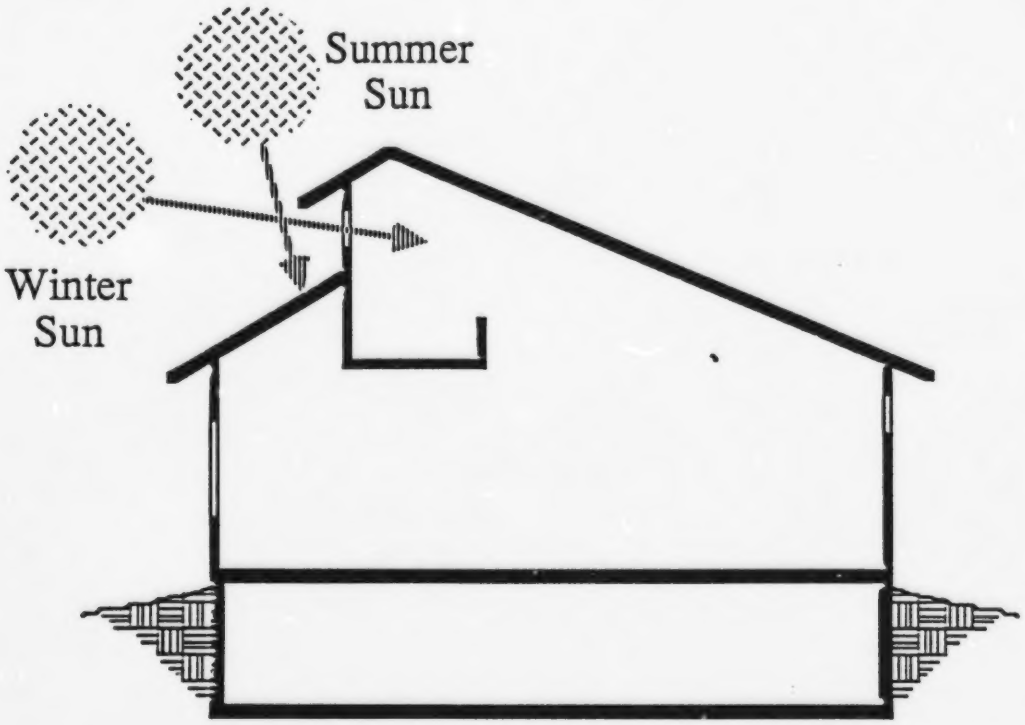
Indirect gain

Figure 7

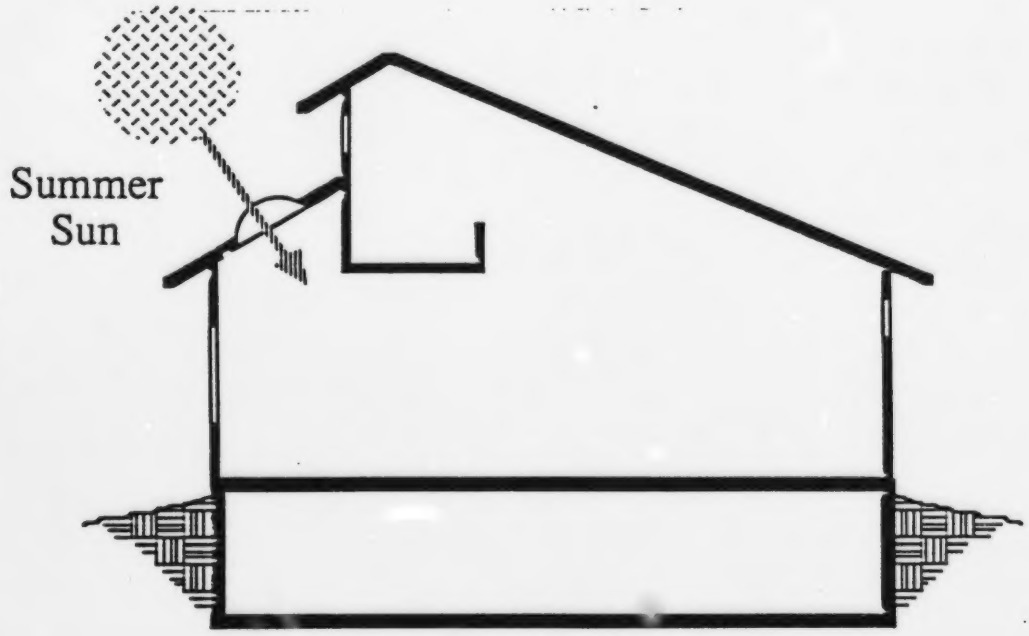
Greenhouses and solariums may be used to collect heat which is then circulated to the living space. The advantage is that greater temperature swings are permissable in an auxiliary space, which does not have to be occupied all the time. By increasing the allowable temperature swings, greater solar utilization is achieved, assuming that there is an efficient method of storing heat and circulating it to the living space. A disadvantage is that the direct gain space is not always at a habitable temperature. If the greenhouse is to contribute to the energy performance of the house, doors and windows connecting it to the house must be closed whenever greenhouse temperatures drop. Auxiliary heaters should not be used to maintain the greenhouse at habitable temperatures, since their use more than offsets any energy savings.

Another indirect gain method which may have advantages in special circumstances is the **Trombe wall**— a south-facing high mass wall of brick, block or poured concrete, surfaced with a dark, selective coating and glazed on the outside. The sun heats the wall which gradually releases the heat to the room behind it. Trombe walls may be practical for some urban situations where, for reasons of privacy or noise, south glass is inappropriate and masonry construction desireable. Trombe walls are expensive to build and their measured performance in Canada has been inferior to direct gain systems. The use of highly-insulated glazings and more efficient thermal storage materials may improve their performance in the future.

Figure 8: Clerestory Windows vs. Skylights



Clerestory windows provide light to north rooms and admit little direct summer sun.



Skylights can result in overheating in the summer.

Rule of Thumb for Selecting Type of Gain:

- **Direct gain to the living space is generally the preferred method of collection.**

Aperture Type and Placement

A solar aperture is any glazed opening which admits sunlight. **Vertical glass** is relatively easy to seal and make weathertight . South-facing vertical glass transmits the greatest amount of direct sunlight in the winter, when it is needed, and transmits reflected light from the snow.

Sloping glass or skylights may be architecturally desirable but must be very carefully designed if they are to perform well thermally. Sloped glass loses more heat than vertical glass and admits more sunlight in the summer when the heat is unwanted. The lower the pitch— the closer to horizontal— the worse the performance.

Rules of Thumb for Selecting Type and Placement of Aperture:

- **A vertical, south-facing window is the preferred solar aperture.**
- **Sloped glass or skylights should be at least as insulative as the other windows in the house. It may be necessary to use light- reflective glass to reduce solar transmittance.**

Figure 8

There are techniques that can be used to admit south light to the north side of the house:

1. **South-facing clerestory windows** in the roof may be used to admit south light to the rooms in the north zone of the house. Design 4 uses clerestory windows to illuminate and heat the second floor play area and the main floor dining room.
2. **Cupolas and raised dormers** may be used to achieve the same effect.
3. **Solar Bays** may be used on east and west walls to admit south-east and south-west light respectively. Solar bays are particularly useful for side-yard walls where the view due east or west would be of the neighbour's house.

These techniques are beneficial because solar heat gains are distributed more evenly about the house and natural light is provided to rooms on the north side, without the energy cost associated with north-facing windows. Relocating glass from the north to the south wall saves about 1GJ /m^2/year.

R-Values and Solar Transmission Coefficients

Conventional	Low E	Low E with Argon
1 RSI .35 S.C. .87 Double	3 RSI .52 S.C. .71 Double	5 RSI .70 S.C. .71 Double
2 RSI .54 S.C. .78 Triple	4 RSI .69 S.C. .65 Triple	6 RSI .76 S.C. .65 Triple

- Window spacing is 12 mm.
- Edge losses are not included.
- S.C., the solar shading coefficient, is the ratio of solar energy transmitted to that for single glazing.

In selecting a glazing type it is important to consider both its RSI and solar transmission coefficient for passive solar performance. Often there is a trade-off since the addition of an extra pane reduces solar gains. However, the net solar gain is always larger; the benefits in reduced glare and UV increased thermal comfort and reduced condensation, as well as larger net solar gains are sufficiently compelling for homeowners to consider.

Window Selection

Until recently, window selection was a relatively simple matter. For energy-efficiency the best choices were double-glazed or triple-glazed windows with a 12mm or greater airspace, casement, awning or fixed type. For greater solar transmittance and economy, south-facing windows were sometimes double-glazed and other windows triple glazed.

These rules still generally hold true but new products from the window industry are introducing a new era of performance and design flexibility. Some caution is needed in selecting new products, both in ensuring that the design performance analysis is correctly done and that the manufacturer's claims are backed by independent test results.

Glazing Type

For solar performance, glazings are selected for their thermal resistance (RSI value) and solar shading coefficient (S.C.). The shading coefficient is the percentage of energy which can pass through a glazing material. Generally, glazings which have high RSI values have a low S.C., and vice versa. For example, two panes of glass have an RSI of 0.35 and an S.C. of .87. Three panes of glass have an RSI of 0.54 and an S.C. of .78.

Apart from adding extra layers of glazing, there are several other ways of increasing the RSI value of window glass:

1. **Low-emmissivity (Low-E) coatings** applied to glass or plastic film increase the RSI value of the glazing by reducing radiant heat loss through the glass; a coated double glazing has approximately the same RSI value as an uncoated triple glazing (RSI 1.5 for 12mm air space).
2. **Inert gas-charged air spaces** in a sealed-glass unit increase the RSI value by decreasing convection losses. Argon or krypton gas is used and increases the RSI value of a 12mm airspace by about .06. The effect is greater when the gas is added to a low-E sealed unit.
3. **Improved edge-sealing techniques** using non-metallic spacers to reduce heat losses at the edge of sealed glazing units increase the overall performance of the unit. Edge losses can decrease the rated RSI value of the glazing by 10%.

Figure 9

Low-E, gas-charged glazings with improved edge seals provide better net performance than standard glazing in most situations and have the added advantage of lower risk of condensation. Manufacturers are now starting to produce glazings with RSI values approaching 1.0. This may not seem very impressive in comparison to a 150 mm fibre glass batt which has an RSI value of 3.5, but it represents a heat savings of two-thirds over conventional double glazing.

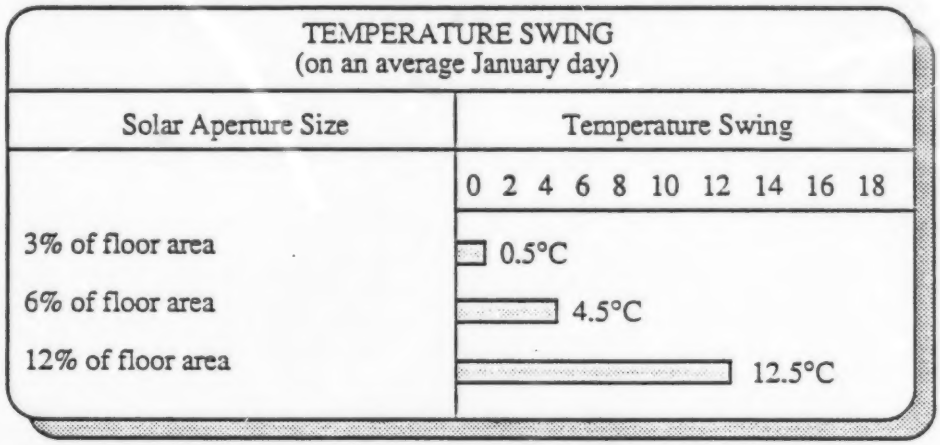
Figure 10: **Design Options Using Grapheat (Effects of Window Area)**

HOUSE SPECIFICATIONS

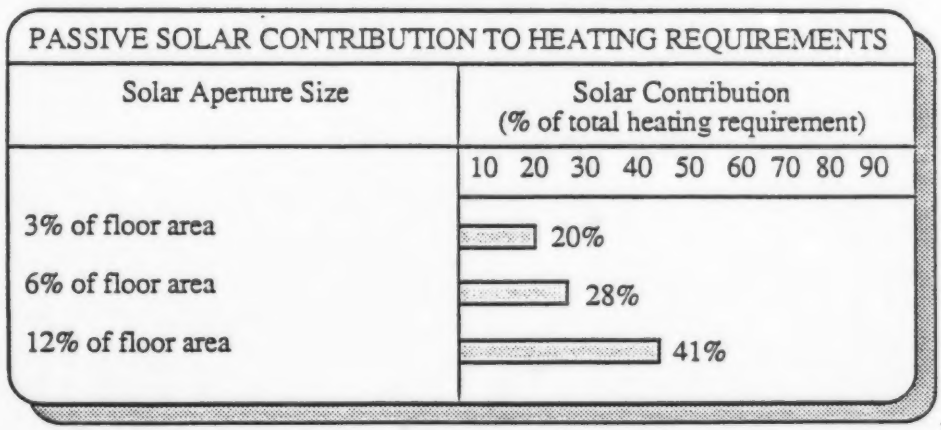
Location: Ottawa
Orientation: Due south
Floor Area: 204 m2
Glazing: Triple
Insulation: Ceiling RSI 10.5, Wall RSI 6.4
Construction Type: Light, (standard drywall, carpeted floor)
Circulation of Solar Gain: Fan Circulation

SOLAR APERTURE SIZE: Three options – 3%, 6%, and 12% of floor area

TEMPERATURE SWING
(on an average January day)



PASSIVE SOLAR CONTRIBUTION TO HEATING REQUIREMENTS



The temperature swing produced by a solar aperture sized at 12% of the floor area is excessive, since a swing of 6°C is generally considered the highest acceptable level. A solar aperture equal to 6% of the floor area makes good use of the sun while avoiding overheating.

Rule of Thumb for Selecting Type of Glazing:

- **In general, a passive solar design performs better with high performance glazing than with standard glazing.**
  Performance analysis will help to determine the best glazing options for individual designs. Figure 9 summarizes the properties of various glazings.

Glazing Size

Choosing the right size of solar aperture is critical to the success of any passive solar design. The acceptable area of south facing glass is dependent upon the shading coefficient of the glazing, the presence of any shading, the local climate, the rate of heat loss from the building, the available thermal storage and the rate of air movement within the building.

Rule of Thumb for Selecting Glazing Size:

- **In most parts of Canada, south-facing solar aperture area— that is the actual glass area— should be equal to about 5%-8% of the heated floor area.**

The 5%-8% rule of thumb provides a useful starting point for a design; it assumes that there is good air circulation within the house to distribute the solar gains and that there is no thermal storage other than that provided by conventional building materials. If there are several rooms on the south side, the glass area should be divided up between the rooms, roughly in proportion to their sizes. The allowable temperature swing governs the glazed area. If the southern glass area exceeds 10%, additional thermal storage must be provided, or the transmissivity of the glass must be decreased. It is important to make sure that the glass area, not the total window area, is calculated; use of the window area will result in insufficient solar gains to the house. Detailed analysis should be used to adjust the final size of the glazed area.

Figure 10

Frame Type

The window frame does not transmit any solar energy, but it may account for more than 25% of the window opening; it should be at least as insulative as the glazed area. Frames which are less insulative than the glass not only lose a lot of heat but are also likely to be cold enough during the winter for condensation or frost to form on the interior surface. Wood frames provide adequate insulation and can be supplied with exterior coatings of plastic or metal to reduce maintenance. Extruded vinyl and fibreglass frames also work well. Metal frames must be insulated and be "thermally broken"— there should be no metal elements which could act as thermal bridges between inside and outside.

Fixed windows are not as leaky as operable windows and generally have a larger glass area than operable windows of the same size. Operable windows tend to become 'drafty' over time as the seals begin to deteriorate. Hinged windows, casement or awning type, have compression seals which generally work better than the seals on sliding windows. Casement windows provide the largest opening for ventilation.

Rules of Thumb for Selecting Frame Type:

- **In general, large windows or glass patio doors are preferred to several small windows because they have a greater proportion of glass area to total window area and receive less shading from the frames.**
- **Frames should be at least as insulative as the glass.**
- **Any window not required to open for ventilation purposes should be fixed.**

Summary

Window sizing, selection and placement are critical to the performance of a passive solar house. The following points should be observed:

1. The simplest and usually the most convenient way to get solar heat into a house is to provide south-facing windows to the living space. Increasing the south window area decreases the purchased energy requirement, especially with RSI 0.5 or better glazing.
2. The majority of the glass in the house should face within 30° east or west of true south. North-facing windows should be minimized.
3. High performance glazings provide a greater net gain than standard glazings and more design flexibility. The more insulative the glazing, the less critical orientation becomes. Double glazing with a 12 mm airspace is a minimum standard.
4. Overheating can be a major problem in a poorly designed solar home. To prevent overheating, the southern glass area should not exceed 5% — 8% of the total heated floor area, unless additional thermal storage is provided.

Figure 11: **The Effects of Circulating Solar Gain**

HOUSE SPECIFICATIONS

Location: Ottawa
Orientation: Due south
Floor Area: 204 m2
Glazing: Triple
Insulation: Ceiling RSI 10.5, Wall RSI 6.4
Construction Type: Light, (standard drywall, carpeted floor)
Solar Aperture Size: 6% of floor area

CIRCULATION OF SOLAR GAIN: Two options – No Mechanical Circulation and Fan Circulation (300 litres/second when required)

TEMPERATURE SWING
(On An Average January Day)

Circulation of Solar Gain	Temperature Swing
	0 2 4 6 8 10 12 14 16 18
No Mechanical Circulation	7°C
Full Circulation	4.5°C

PASSIVE SOLAR CONTRIBUTION TO HEATING REQUIREMENTS

Circulation of Solar Gain	Solar Contribution (% of total heating requirement)
	10 20 30 40 50 60 70 80 90
No Mechanical Circulation	22%
Full Circulation	28%

Circulation of solar gains is obviously desirable. The temperature swing produced when there is no mechanical circulation is excessive, and the useful solar contribution drops.

Unless mechanical circulation is provided, the solar aperture size needs to be reduced to maintain temperature swings within acceptable limits. This, however, would reduce the solar contribution even further.

CHAPTER 3: DISTRIBUTING SOLAR HEAT

Introduction

The previous chapter described ways to admit solar energy to the house. This chapter explains how to get the heat to where it is needed. The best way to ensure that solar heat is distributed throughout the house is to design the house so that each room receives sunlight; more information on direct gain is given below. If direct gain is not practical, the heat must be distributed by other means. Normally, this requires the use of both natural and forced air circulation. Circulation of air from the south zone to other parts of the house helps distribute the solar heat throughout the home and enables the entire house mass to act as thermal storage; it also helps to control temperatures on the south side. Without adequate air circulation it is necessary to reduce the solar aperture size to prevent south zone overheating, which reduces the overall solar contribution.

Figure 11

Daylighting and Direct Gain

Design features such as clerestory windows, cupolas and solar bays can supply southern light into the north zone of the house. In addition, there are interior devices which may be used:

Use of light-coloured surfaces, especially on ceilings, helps to distribute light.

Room layouts which connect north and south sides of the house with large openings are good; glazed **french doors** may be used for sound isolation.

Deadlights are 'windows' in interior walls which allow light from a well-lit space to illuminate a second area. **Glass block** is often used for this purpose. Stairwells, kitchens, laundry areas and showers are all spaces which may be lit and heated in this manner.

If ceilings are above standard height, **transom lights** may be used immediately below the ceiling, above eye level. Transom lights are particularly effective when used in conjunction with clerestory windows and light-coloured sloping ceilings. Light from the clerestory is reflected along the ceiling plane and through the transom into the room beyond.

Light shelves and louvres may be used to enhance the effect.

Natural Convection

When air becomes warm it expands and rises, whereas cooler air flows downwards. This natural convection cycle is a powerful force which may be used to advantage in a passive solar home. Natural convection may be used to circulate solar-heated air about the house and simultaneously to cool the south zone. If natural circulation only is to be used, the following techniques should ensure adequate heat distribution:

Rules of Thumb for Natural Circulation:

- **Compact plans lend themselves to good natural circulation;** little natural circulation will occur between rooms on opposite ends of an elongated ranch-style home.
- **Open plans in which the south rooms connect to the stairwell or to another double-height space work best.** All the detached house designs in this book have this feature.
- **Natural convection can be improved by designing uninterrupted flat or sloping ceilings for the air to flow across.** If the need for visual privacy precludes the use of open plan design, partitions may be terminated a few inches below the ceiling.
- **Cross-over registers** may be used in ceilings and floors to permit air to rise from one room to another.

The techniques which give good natural circulation also allow good sound transmission. Sound baffles which cut off direct paths of transmission with sound-absorbing material may be necessary for bedrooms and other areas where sound isolation is important.

Forced-Air Circulation

Natural convection may be supplemented by mechanical means. If the house is to have a forced-air heating or air-conditioning system, the same blower and ductwork may be used to move solar-heated air. This solar circulation is normally done by locating the main air return for the system at the top of the house where heated air tends to collect. Design 1 has this type of distribution system. The furnace blower draws the air through the return air duct and distributes it to the supply registers in each room. A forced-air heating system is a convenient means of distributing passive solar gains about a house. There are few additional costs involved since the major components— furnace and ductwork— are required anyway. The ducts deliver air to each room and the amount of air can be adjusted using the register dampers. The entire process of solar-gain distribution takes place automatically and, if a heating source such as a wood stove is located in the area of high passive solar gain, heat from the stove will also be circulated.

Natural air circulation in passive solar houses without a forced-air heating system can be assisted by ceiling fans or by blowers:

1. **Ceiling fans** are appropriate for high-gain areas where the cooling effect of moving air is desirable.
2. **Blowers** may be used to move the heated air from the south zone to the rest of the house. A full duct system is not necessary; sometimes it is possible to use a single central ceiling plenum to supply air to both lower and upper non-solar rooms.

Rules of Thumb
for Forced Circulation:

- **Locate supply registers high in the walls or ceilings to prevent discomfort due to drafts from registers.** Re-circulated air will be at a lower temperature than furnace-heated air, particularly if the distribution ducts are also used to supply fresh ventilation air.
- **The furnace blower may be operated either continuously or be controlled by a cooling thermostat located near the main return.** The thermostat should be wired so that it turns the blower on — but not the furnace— when temperatures rise above a comfortable level. Multi-speed blowers give the system more flexibility.

Sizing

It is important not to underestimate the airflow needed to maintain comfortable temperatures in the passive solar areas.

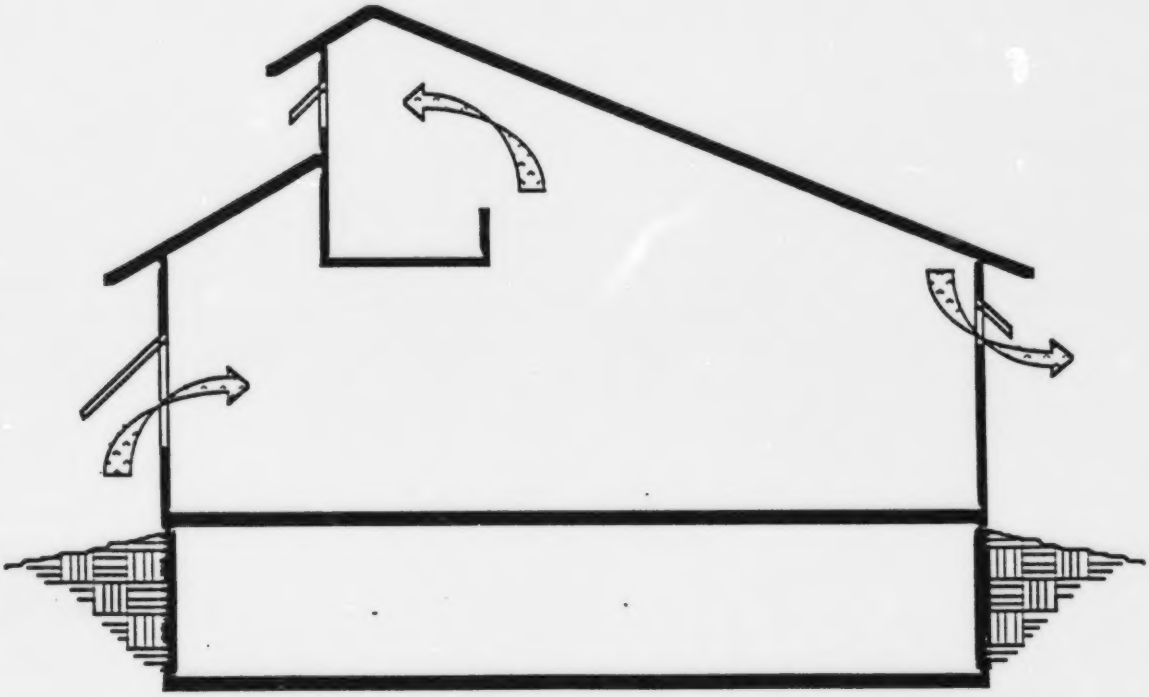
Rule of Thumb for
Sizing:

- **Where it is necessary to use mechanical circulation to reduce overheating, 20 to 40 litres per second should be provided for every square metre of solar aperture.** A standard furnace fan is generally adequate. The analysis tool GRAPHEAT, or standard engineering procedures, should be used to determine airflows for final design purposes.

Ventilation

Like other houses, passive-solar houses need ventilation during the winter months to maintain good air quality. In the summer, ventilation is required for cooling. Many energy-efficient houses have central, fully ducted, mechanical ventilation systems which supply fresh air to the house and exhaust stale air. Because the airflow rates required for ventilation are considerably less than those needed to distribute passive solar gains, ventilation systems are not an appropriate method of distributing solar heat. However, a central ventilation system with a heat recovery ventilator (HRV), is a good way to provide better indoor air quality in a passive solar home. Monitored R-2000 houses with HRVs have been found to have lower levels of indoor air contaminants than conventional houses without automatic forced ventilation systems.

Figure 12: Summer Ventilation



Natural ventilation may be achieved using low and high operable windows and/or windows located to direct breezes.

Figure 12

Rules of Thumb for Ventilation:

- **A properly designed and installed central ventilation system with a heat recovery ventilator (HRV), is recommended practise.**
- **Summer cooling ventilation is most easily handled with operable windows.** Ideally, these are located so that the prevailing summer breezes assist natural circulation; air enters the house low on the windward side and exits high on the leeward side. If this is not feasible, it is usually possible to arrange for good cross-ventilation so that air moves diagonally across each room.
- **Windows should be opened at night and closed during the day in hot weather.**
- **Air-conditioning can replace natural ventilation during the cooling season, in which case mechanical ventilation is needed to provide fresh air.**

Summary

Good heat distribution is essential to passive solar design. It is achieved by:

1. Designing the house so that as many rooms as possible receive direct sunlight.
2. Designing the house so that air circulates naturally from areas receiving the most sunlight to areas receiving the least.
3. Using the forced-air heating system or other mechanical equipment to assist the natural circulation process if necessary.
4. Using thermal analysis tools to estimate the required airflow rates and to size equipment.

Figure 13: . The Effects of Providing Heat Storage

HOUSE SPECIFICATIONS

Location: Ottawa
Orientation: Due south
Floor Area: 204 m2
Glazing: Triple
Insulation: Ceiling RSI 10.5, Wall RSI 6.4
Circulation of Solar Gain: Fan Circulation
Solar Aperture Size: 12% of floor area

CONSTRUCTION TYPE: Two Options – Light (standard drywall, carpet), and Heavy (double drywall, hardwood floors)

TEMPERATURE SWING
(On An Average January Day)

Construction Type	Temperature Swing
	0 2 4 6 8 10 12 14 16 18
Light	12.5°C
Heavy	5.0°C

PASSIVE SOLAR CONTRIBUTION TO HEATING REQUIREMENTS

Construction Type	Solar Contribution (% of total heating requirement)
	10 20 30 40 50 60 70 80 90
Light	41%
Heavy	42%

With light construction, the temperature swings produced by a solar aperture sized at 12% of the floor area are excessive. The same solar aperture produces acceptable temperature swings in a house with heavy construction because the heavy construction provides heat storage. In other words, the heavy construction makes it possible to increase the solar aperture size. As a result, the solar contribution rises to 42% of heating requirements as compared with 28% for a solar aperture of 6% of floor area. However, this large increase in solar contribution does not result in a significant reduction in space heating load since the additional heat loss of the larger glass area offsets the increased solar gain. High performance windows with triple glazing are necessary for achieving large energy savings using increased solar aperture and mass.

CHAPTER 4: STORING SOLAR HEAT

Introduction

The previous chapters dealt with the collection and distribution of solar heat for immediate use within the house; the other essential component of a passive solar system is thermal storage. When sunlight is converted to heat within a material, that material functions as thermal storage. Lightweight building materials have little thermal capacity and radiate the heat to the room almost as soon as they receive it. Massive materials absorb the heat and release it slowly over a longer period of time. The presence of thermal storage materials in rooms receiving sunlight reduces the size of the temperature swing and stores passive solar heat until later in the day. Adequate thermal storage is necessary in a passive solar house to maintain comfortable temperatures and to provide heat during non-solar periods.

Figure 13

Storage materials

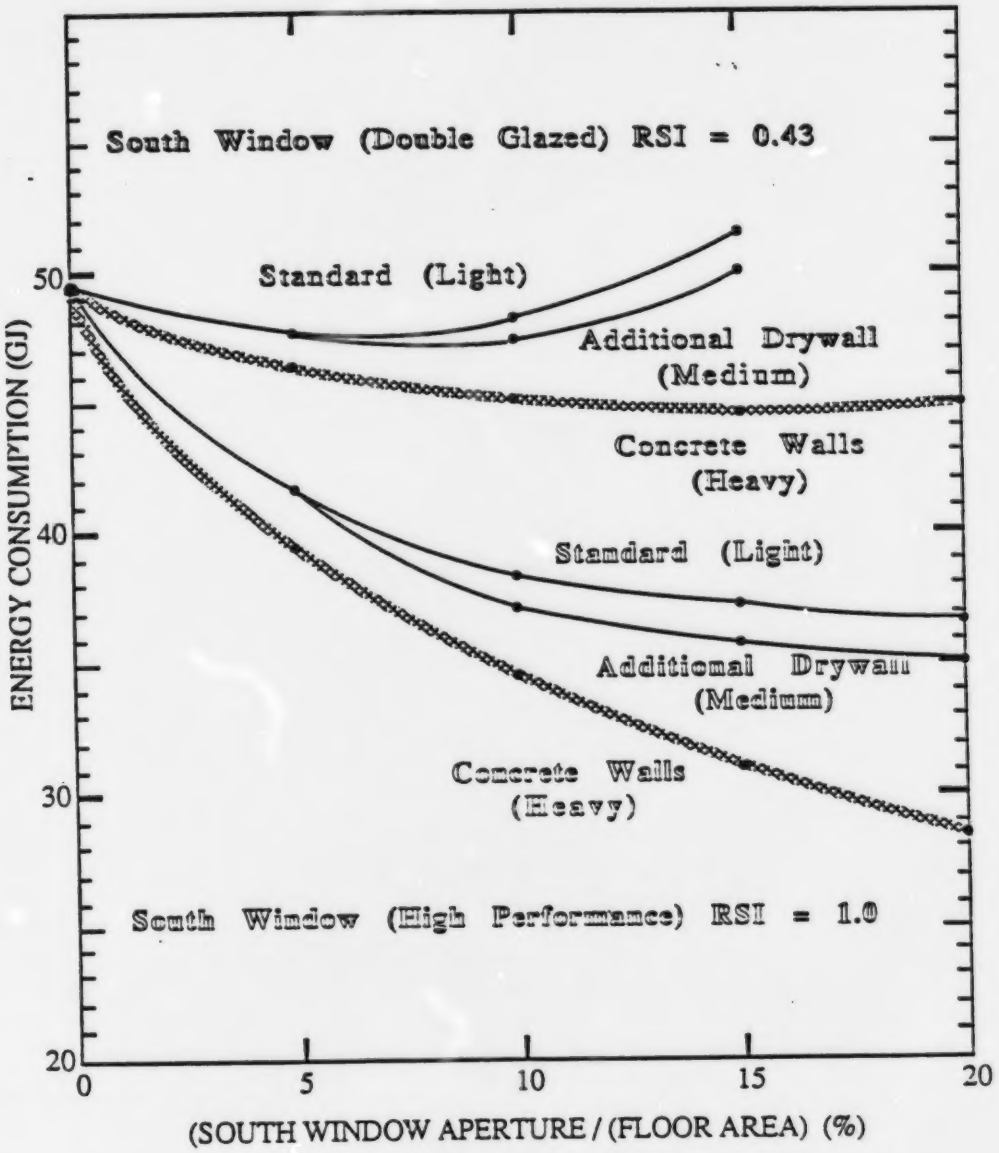
The amount of heat an object can store is principally related to its size and heat capacity (the amount of heat that the material can store). The more thermal mass that is provided, the more storage that is available. It is important, however to ensure that the material not only has a large storage capacity but also that it is able to conduct heat readily to its interior. Dark colours absorb and radiate heat better than light colours but reflect light poorly. Generally, light colours are preferable for good light distribution, even though they offer a marginally less-effective thermal storage capability. The exception might be a dark-surfaced feature wall in a well-lit building.

Plasterboard provides a low-cost thermal storage material and is the most convenient and practical material to use in most situations. Simple thermal analysis tools generally assume an interior plasterboard finish. The thermal capacity of plasterboard may be increased by using a thicker board, by using a double layer or by applying plaster over the plasterboard. These techniques are sometimes used in conventional houses because they are considered to provide a superior finish.

Masonry Brick, stone and ceramic tile are good thermal storage materials. Ceramic tile floors may be used in south-facing rooms. Brick or stone feature walls have often been used to augment the thermal storage in a passive solar house.

Water has excellent heat storage characteristics but is not the easiest material to incorporate in a room. In greenhouses, water containers are sometimes stacked against the back wall and freestanding translucent tubes filled with water have been used. Decorative, water-filled containers have been used in living spaces as thermal storage. Indoor swimming pools make good thermal heat sinks. Hot tubs and spas do not work effectively as direct storage because the water is maintained considerably above room temperature.

Figure 14: **Effect of Thermal Mass on Building Energy Consumption (Low Heat Loss Windows)**



Note that with double glazed windows (RSI 0.43) the addition of mass improves energy savings but there is no significant savings beyond 6% south window/floor. With high performance windows, additional mass contributes to savings well beyond 10% but control of temperature swings becomes a problem.

Phase-Change Materials. A phase change material (PCM) absorbs heat as it changes from a solid to a liquid or from one solid crystalline form to another, and releases heat when it changes back to its original form. When a material melts, it absorbs heat from its surroundings, yet its temperature does not change. For example, a glass of ice water in a warm room will absorb heat from the room, which causes the ice to melt. However, the water temperature will stay the same — 0 ° C— until all the ice has melted.

Materials which "melt" at room temperature can be used to store solar heat. The advantage of PCMs in a passive solar house is that they can store much more heat per unit volume than materials which rely on mass alone, and they do it with little increase in temperature. The PCMs used for passive solar storage are usually waxes or mixtures of mineral salt crystals and have been sold in manufactured modules. Manufacturers are currently investigating the feasibility of incorporating PCMs in common building materials such as plasterboard and concrete block. If this research is successful, phase-change-enhanced thermal storage is likely to be an excellent method of achieving increased passive solar contributions.

Figure 14

Rules of Thumb for selecting Storage Materials:

- **For increased comfort, use thicker than normal plasterboard in the south zone of the house.**
- **If massive masonry materials are to be used as finishes for aesthetic reasons, it makes sense to place them so that they also function as thermal storage.**
- **In general, water is best used as remote storage in conjunction with a heat pump.**

Storage location

A practical arrangement is to design the house so that rooms receiving direct sunlight contain additional thermal storage materials. A double layer of plasterboard is often used for this purpose; decorative elements such as a masonry fireplace may also be incorporated. If further storage is required to utilize excess solar gains and control temperature swings, forced-air blowers may be used to drive solar-heated air to remote storage locations.

Rules of Thumb for Storage location:

- **Storage materials are most effective if placed in direct sunlight.**
- **The larger the surface area the better; large, thin sheets of heavy materials are preferable to small areas of thick (over 100mm) material.**
- **Thermal storage materials become ineffective when they are covered with insulative materials such as carpet.**

Mechanically Enhanced Storage

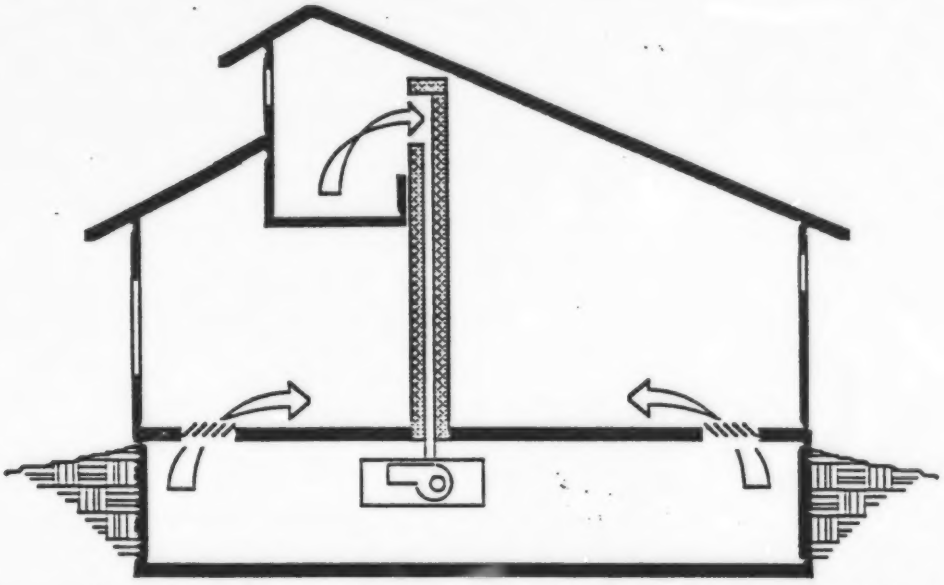
If the design requires more thermal storage than can conveniently be accommodated in the solar zone of the house, additional storage may be placed elsewhere.Thermal storage can be made to function effectively away from direct sunlight provided sufficient heat can be moved to the storage. This heat transport normally means using blowers and ductwork to move large volumes of solar-heated air from the south zone of the house to the storage location. Depending on the type of storage, stored heat may be released by passive discharge or by mechanical means.

Air-coupled remote storage. Either massive materials such as concrete and crushed stone or phase-change materials are used for this type of storage. The material must be at a lower temperature than the air used to heat it and must be warmed above room temperature before the heat can be used for space heating. To charge the storage, warm air must flow over the surface of the mass; the greater the surface area exposed to the heat, the faster the heating process. Extra-thick or double plasterboard applied to the north zone of the house is a practical type of remote storage, particularly if thick plasterboard is also required for other reasons.

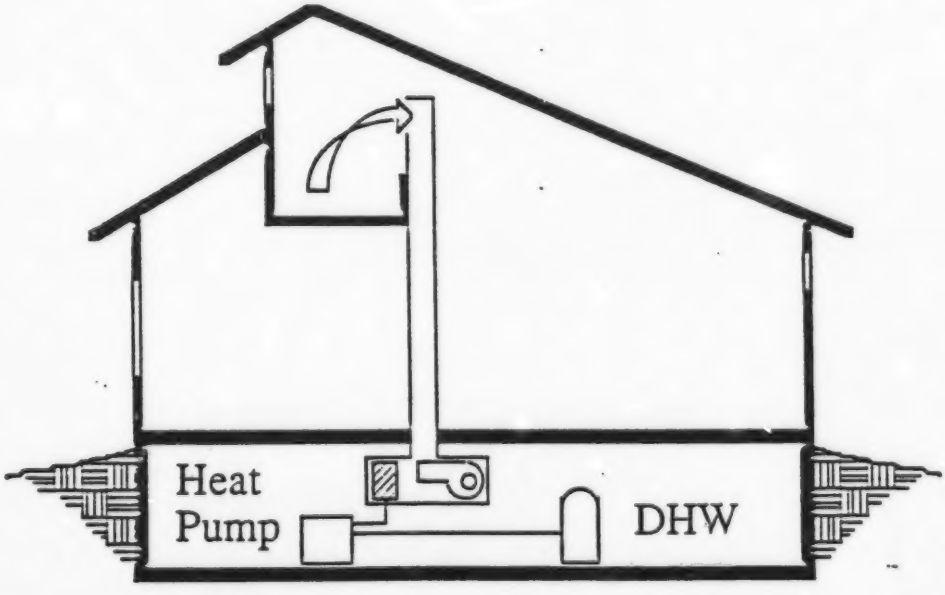
Basement Storage Since most houses have concrete or block basements, it would be convenient to use this mass for thermal storage. However, there are problems with this approach. Condensation may occur on the surface of the concrete if basement temperatures are much lower than the solar-heated air and humidity levels are high. If a basement or crawl-space is fully insulated on the exterior and under the floor to reduce heat loss and risk of condensation, it may be treated as a pressurized plenum and used to store heat. This solution is useful in some circumstances.

Rock bins have been used for thermal storage and may be appropriate for greenhouses or sunspaces where wide temperature fluctuations are experienced. **Hollow core concrete slabs** have also been used. In this system, the warm air is blown through the hollow floor slab, which becomes warm and eventually warms the rooms above and below. Either type of storage is unlikely to be cost-effective, although its utility is increased if a second, preferably relatively high temperature heat source such as a wood stove, is used to charge the storage when solar heat is unavailable.

Figure 15: Mechanically Enhanced Storage



Solar gains may be stored by circulating warm air through thermal mass and distributing it throughout the house



Heat pumps may be used to extract heat from room air and used to heat hot water or stored for space heating

Heat-pump-augmented Storage

Water is one of the most efficient thermal storage materials and a heat-pump is a highly effective means of transferring solar gains to water storage. Another advantage of heat-pump-augmented storage is that the heat-pump upgrades low temperature passive solar heat to much higher temperatures which can be used for a variety of purposes. Heat-pumps enable solar heat to heat domestic hot water, to provide hydronic space heating or to heat swiming pools and indoor spas. A heat-pump produces cooling as a by-product of the heat transfer process. This cooling is convenient for passive solar applications because the cool air may be used to offset any overheating during solar gain periods.

Figure 15

A few manufacturers offer air-to-water heat-pumps suitable for passive solar homes. A passive solar installation is unlike a conventional air-to-air heat-pump in that it draws warm air from inside the house and transfers the heat to water storage. The system configurations differ by manufacturer but the pump itself is not normally reversible; the heat is extracted from the hot water tank by drawing the hot water off, in the case of domestic hot water, or is pumped through a fan coil unit or radiators for space heating. While it is not necessary for most passive solar houses, heat-pump-augmented storage is an important tool for the designer who wishes to maximize passive solar contributions.

Summary

Thermal storage is required in every passive solar house. If the house has a modest amount of south glass, standard building materials may provide sufficient mass but often additional storage is required. There are several methods of providing storage and it may be more convenient to use two or more techniques in the house rather than attempt to meet all storage needs with one material. The following points may assist the selection of storage methods:

1. The first step is to increase thermal mass in rooms receiving direct sunlight. Thicker than normal plasterboard, ceramic tile floors and masonry feature walls may be used.
2. If analysis shows that more storage is required, mechanically-assisted remote storage may be used. Heat-pump systems using water as a heat sink have the greatest storage capacity.

CHAPTER 5 DESIGN INTEGRATION

Introduction

The one thing that makes or breaks any house design is the way in which the various functions and systems fit together to make an architectural whole. This fit is particularly true of a passive solar design which must incorporate solar collection, air circulation and thermal storage along with all the other items needed in the house. Careful foresight rather than capital expense is needed to make a passive solar design work, and the thermal analysis tools now available to the designer make the task relatively easy.

Interior layout

The interior layout of a house affects the way the passive solar components work. To summarize the points raised in previous chapters, these guidelines should be followed:

Rules of Thumb for Interior Layout:

- **As much of the house as possible should receive direct sunlight.** In particular, the primary living space—living rooms, dining rooms, great rooms and family rooms—should receive direct sunlight.
- **Open planning, rooms which extend the entire depth of the house from north to south, open stairwells, and double- height atriums help to distribute heat and sunlight through the house.** However, houses in which most of the lower floor is open to above will tend to be warmer upstairs than down unless fans or blowers are used to distribute the air.
- **Interior masonry feature walls should be located in the south zone of the house in rooms receiving direct sunlight.**
- **Windows should be kept to a minimum on the north elevation.** Large expanses of west-facing glass should be avoided. Windows on the other walls should optimize glass area; for any given frame opening, one large window performs better than several small ones. Highly insulative glazings give better overall performance than conventional glazings.

Matching collection, circulation & storage

These three variables must match; it is useless to have a large expanse of south-facing glass with no air circulation and no thermal storage because the south part of the house will overheat. Conversely, high-volume blowers and massive masonry feature walls will accomplish nothing if there is insufficient south window area or if the glass is shaded. Obeying the rules of thumb regarding collection, circulation and storage should result in a design which is close to the mark. Thermal analysis is then used to fine-tune the plans.

Heating, Cooling & Ventilation system considerations

A passive solar house requires an auxiliary heating system when solar energy is not available and passive solar storage has been depleted. Depending on the design, about 60% to 75% of the annual space heating requirements will normally be supplied by the auxiliary heating system. Any medium-or high-efficiency heating system may be installed in a passive solar house. The choice of heating system is dependent on the house design. For example:

Baseboard electric resistance heaters may be the best choice for a well-insulated, modest, low-load/ low-gain house with good natural air circulation.

If natural air circulation is insufficient,, a **forced-air furnace** can do double duty by providing auxiliary heat and air circulation; a further advantage of a fully-ducted heating system is that the ducts can also be used to distribute fresh ventilation air.

In houses with low heat loads, **domestic hot water tanks** have been used to provide both hot water and space heating by running a hot water line from the tank to a **fan-coil unit** which distributes warm air to the house through a conventional duct system.

Radiant heating panels can be useful, particularly in sun rooms, where they can be used at night to offset any discomfort caused by large expanses of glass.

Elaborate house designs with much glazing and luxury features such as spas or swimming pools generally require elaborate mechanical systems. Both indoor and outdoor swimming pools have been used as heat sinks, or thermal storage, in conjunction with **water-source heat pumps.**

All passive solar houses require some form of air circulation during collection periods to distribute warm air about the house and to cool the south zone of the house. This **'passive cooling'** will in most cases be adequate all year; a well-designed passive solar house should not become too warm in any season. During the summer, windows may be opened at night to cool the house and closed, with curtains and blinds drawn, during the day. If air-conditioning is required, an air-to-water heat pump may be appropriate. Some of the new systems can be set up to supply space heating and hot water, cooling and thermal storage.

A forced-ventilation system is needed to supply fresh air to the living space and to exhaust stale air. A convenient way to get an energy-efficient central ventilation system is to install a **heat recovery ventilator (HRV).** Balanced-flow HRVs heat incoming fresh air with outgoing stale air ducted from bathrooms and kitchens. **Exhaust-only ventilation systems** which employ

heat-pumps to recover heat are also available; fresh air must be introduced separately with these systems. Several publications on house ventilation and HRVs are listed in the reference section at the back of this book.

Energy-Efficient envelope design

A passive solar house must also be an energy-efficient house if it is to function properly. The exterior envelope (foundations, walls and roof) must be well-insulated with minimal thermal bridging through assemblies, and must be highly resistant to air-infiltration or exfiltration. Several good techniques for building energy-efficient wood frame housing have been developed in recent years and have been described in detail in the publications listed at the back of this book. It is most important that both the designer and the builder be thoroughly familiar with energy-efficient construction practice. Optimum insulation levels for a particular design depend on many factors, including fuel cost, materials cost and desired payback period. Thermal analysis will help to determine the best strategy.

Design for Comfort— A Comfort Checklist

Comfort involves a number of variables, not the least of which are the occupants themselves, each of whom may have different ideas regarding ideal temperatures, humidity and lighting levels. However, if the house and its mechanical system have been properly designed, the occupants should be able to control the indoor conditions to suit themselves.

Winter overheating

No part of the house should become uncomfortably hot during the heating season. A balance must be found between solar aperture size, heat storage capacity and air circulation. In particular, the latter should distribute the solar gains and prevent hot spots from developing.

Summer overheating

The passive solar house should be designed to function without air-conditioning in the summer. The glazing should be equipped where necessary with awnings, overhangs and blinds. Operable windows should be located to facilitate good cross-ventilation and the house layout should provide good natural air-circulation. If air-conditioning is required, it may be added to the forced-air heating system, as in a conventional home. If an air -to-water heat-pump is part of the mechanical system, it can be used to provide air conditioning.

Winter chilling

The house should not become uncomfortably cool at night. The thermal envelope must be well-insulated and precautions should be taken to prevent localized cooling at windows. Radiant heat loss

through glass at night can cause discomfort to people sitting close to the windows, even if air temperatures are high. Also, the cool glass surface tends to create convection currents which are perceived as drafts, even if the window is airtight. The use of blinds and drapes may cure this problem. Alternatively, wall-or ceiling-mounted radiant heating panels may be used as supplementary heaters to counteract the effect of radiant losses through the glass. Highly insulated glazings are less likely to cause discomfort than conventional glass.

Air movement

Forced-air circulation should not create discomfort. Moving air feels cooler than still air at the same temperature. Therefore, when a fan is being used to move air at room temperature about the house, the occupants may perceive the air movement as drafts, especially if they are seated near a floor register. Drafts may be prevented by placing the supply registers in the ceiling or high in the wall. Air-conditioning diffusers rather than heating register grilles help to disperse the moving air in a draft-free manner.

Humidity control

The house should have moderate winter humidity levels, about 40% RH. Air with a high relative humidity feels warmer than dry air at the same temperature and permits the thermostat setting to be lower, but very high relative humidities are uncomfortable and may lead to condensation damage on the windows and other surfaces. Energy-efficient construction practice reduces unwanted natural air-infiltration and raises indoor winter humidity levels. The controlled ventilation system provides an effective means of adjusting indoor humidity; if humidity levels are too high, the ventilation rate is increased, if they are too low, the ventilation rate is decreased. Adjustment of the ventilation rate should result in comfortable conditions in the majority of houses.

In the case of large houses, or houses without children where the occupants are at work all day, humidity levels are sometimes too low, even after ventilation rates have been decreased. Lifestyle changes, such as the addition of house plants to the home and the venting of electric clothes dryers indoors, may solve the problem. If not, a humidifier can be used. Excessive humidity is unusual and may be a sign that the ventilation system is undersized or malfunctioning.

Air Quality

The air inside the house should be perceived as "fresh" rather than stale with lingering odours. Fireplaces must be equipped with a ducted outside air supply and glass doors to reduce the risk of combustion products entering the living space. When heating with gas or oil, use the new high-efficiency furnaces and boilers which have a fan to maintain draft, or have a sealed combustion air intake, to avoid the possibility of backdrafting or spillage of the products of combustion. It is good practise to seal basement cracks and floor drains to prevent the entry of radon or other soil gasses. The ventilation system should be designed to supply fresh air to the

whole living space, especially to living rooms and bedrooms. Stale air should be exhausted from kitchen, bathrooms and hobby areas before it contaminates the rest of the house. Paint and other construction materials should be allowed to cure and the house should be thoroughly ventilated to remove all odours prior to occupancy. Air filters can be installed in the ventilation system for people particularly sensitive to dust, pollen and other particulates.

Glare

The house should be designed to reduce discomfort from glare. Glare may be a problem in rooms with very high lighting levels but it more commonly occurs in rooms with high lighting contrast, particularly if the subject is focussing on an object in shadow against a bright background such as a window. Risk of glare is reduced if windows are placed on more than one wall to provide cross-lighting. Walls adjacent to windows should be finished with light colours to reflect light. Reading and sewing rooms and studies should be organized for even light distribution.

Summary

This chapter concludes Part I of this book. Much of this information represents good design practise for any house, but the passive solar designer, or potential homeowner, must pay particular attention to the integration of passive solar features into the house and their likely overall effect on the various comfort parameters. This concern is necessary partly because a passive solar house should have superior comfort and energy performance, and partly because failure to balance collection, distribution, storage and the other aspects of energy-efficient design can result in occupant discomfort and unnecessarily high energy use. Analysis tools should always be used to assess the performance of a design prior to construction.

Further Information

GRAPHEAT is a simple method for quickly estimating passive solar performance. The GRAPHEAT method is described in two CMHC publications: GRAPHEAT and GRAPHSHADE, available from Canada Mortgage and Housing Corporation.

HOT-2000 (early versions are known as HOTCAN) is the easiest to use and quickest of the available microcomputer programs. HOT-2000 is available from Anderson Techno-Products, 947 Richmond Road Ottawa, Ontario K2B 6R1.

ENERPASS is a computer program which gives hour by hour simulations in addition to seasonal totals. It is suitable for analysing complex designs or for checking outputs from other programs, particularly when unusual design strategies are employed. ENERPASS is available from Enermodal Engineering, 368 Phillip Street, Unit 2, Waterloo, Ontario N2L 5J1.

HEAT RECOVERY VENTILATORS Performance comparisons can be made between units on the market using test results in accordance with CSA Standard 439. Installation should be in accordance with CSA 444. Information may be obtained from The Heating, Refrigeration and Airconditioning Institute of Canada, 5468 Dundas Street West, Suite 226, Islington, Ontario M9B 6E3.